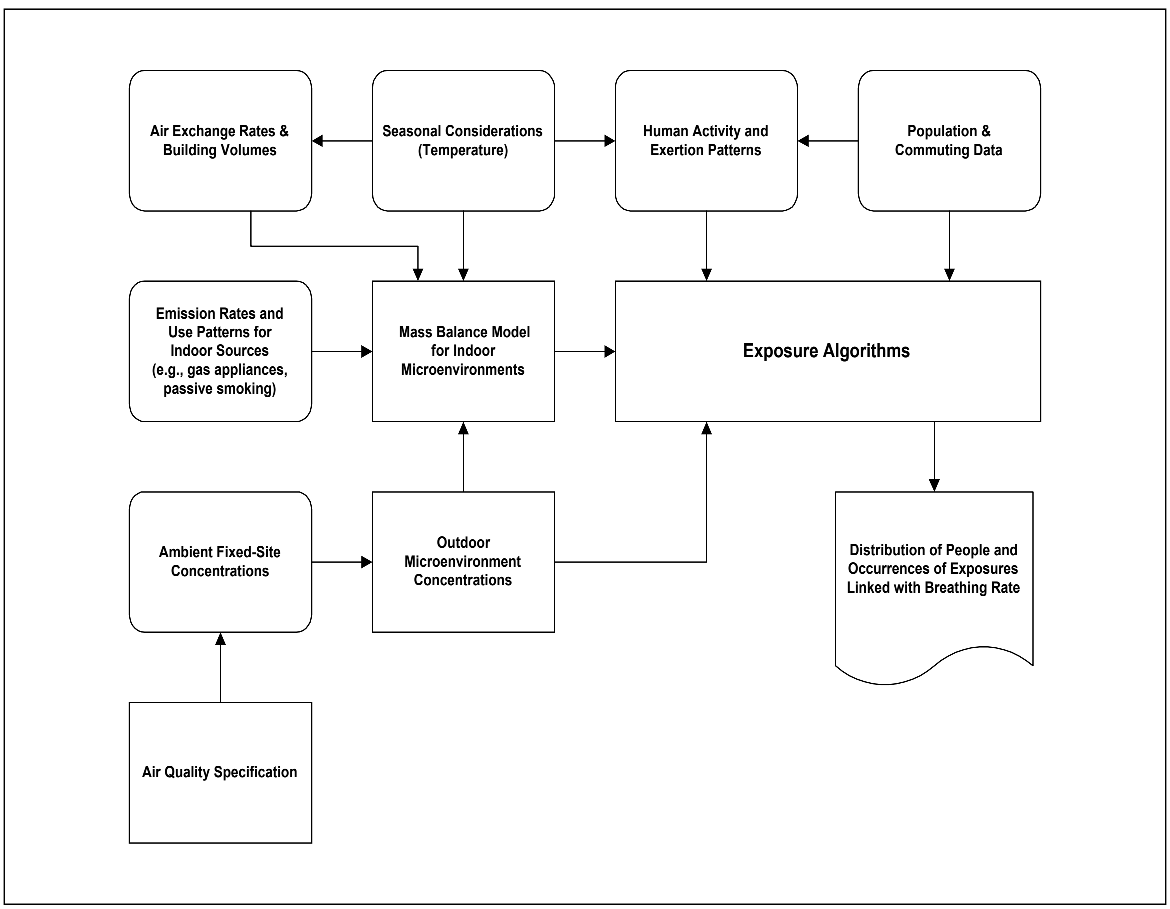
5. INHALATION

This chapter provides details of the inhalation component of TRIM.Expo. The structure of the inhalation component will be consistent with the conceptualized framework for TRIM.Expo described in Chapter 4. In addition, the initial development of the inhalation component will be based on the logic of pNEM. This will provide a firm scientific foundation for TRIM.Expo's inhalation exposure algorithms, so that they are responsive to OAQPS' need for a scientifically-sound, human exposure model for inhalation.

5.1 OVERVIEW OF THE APPROACH

Because of the flexible structure of TRIM.Expo, when performing an inhalation exposure assessment, the user must make a number of selections regarding the input parameters. The following six subsections provide the generalized approach for modeling inhalation exposures in TRIM.Expo. This approach is adopted from pNEM/CO (Johnson et al. 1999). Figure 5-1 is a schematic representation of the various input parameters and the resulting output of pNEM/CO.

Figure 5-1
Schematic Representation of the Input Parameters and Resulting Output of pNEM/CO



5.1.1 SELECTION OF STUDY AREA

The study area for inhalation exposures can be user-defined so long as estimates of outdoor air concentrations for the pollutant(s) of interest are available. The data on outdoor concentrations can be taken from ambient, fixed-site monitors or alternatively can be calculated using either an air quality dispersion model (*e.g.*, the Industrial Source Complex, or ISC, model), TRIM.FaTE, or other air quality models. In TRIM.FaTE, the ambient air compartment is characterized in terms of its gas phase, particulate matter, and water composition.

The study area is divided into exposure districts. The exposure districts are spatial areas with defined boundaries (either physical or political). If ambient monitoring data are used, then the exposure district may be defined as the area within a given distance of the monitor. If modeled air quality data are used, the exposure district can be defined according to the resolution of the modeled data. Modeled air quality data that are organized in a gridded pattern can have the exposure districts defined for each modeled grid-square or for aggregations of grid squares. Alternatively, a modeled grid-square value can be associated with a geopolitical area for which demographic information is available. For example, a modeled value could be assigned to the census-tract to which it belongs, thus relating calculated outdoor concentrations to the population information specified in census data.

5.1.2 SELECTION OF POPULATIONS OF INTEREST

When conducting an exposure assessment using TRIM.Expo, the user may select a specific population group, or a set of groups, for which exposures will be estimated. Groups can be defined by any number of attributes including age, gender, family income, work status, health status (*e.g.*, heart disease patients), or proximity to particular emission sources (*e.g.*, natural gas cooking fuel). Since the movements and daily activities of the population of interest will determine which exposure media the individuals contact and in which exposure districts the contacts occur, data about the behavior of the population are required. Typically, the entire population for all of the exposure districts in the study area is included. Then, through the selection of cohorts, discussed below, exposure for subsets of the population are estimated. Characteristics for defining cohorts can be geographic factors, demographic factors, or both. Alternatively, the user may specify a set of individuals for an exposure assessment. In this case, the user supplies additional information about the individuals, as discussed below.

5.1.3 DEFINITION OF POPULATION COHORTS

For an exposure analysis using groups, the population of interest, once chosen, is divided into groups with similar attributes; these groups are called cohorts. Each cohort is assumed to contain persons with similar exposures that are taken from the same probability distribution. Each person is associated with only one cohort. The use of cohorts is a useful technique when estimating the exposures of a large population with inadequate information about each individual's activity profile. Aggregating information about people who are expected to have similar exposures makes better use of the limited data that are available.

Cohort exposure is typically assumed to be a function of demographic group, location of residence, and location of work or school. A demographic group is comprised of all individuals that share one or more demographic features, such as a particular age (or age range), gender, ethnic background, or occupation. Specifying the home and commuting district of each cohort provides a means of linking cohort exposure to ambient concentrations. Specifying the demographic group provides a means of linking cohort exposure to activity patterns that vary with age, work or school status, and other demographic variables. In some analyses, cohorts are further distinguished according to factors relating to proximity to emission sources (*e.g.,* an indoor source such as a gas stove) or time spent in particular microenvironments.

5.1.4 DEVELOP AN INHALATION EXPOSURE-EVENT SEQUENCE FOR EACH COHORT

When performing an inhalation exposure analysis using TRIM.Expo, information is needed about each "location" that each individual or cohort visits during their daily activities (*e.g.*, in the kitchen at home, outdoors at school, indoors at work). These locations are called microenvironments. An important feature of TRIM.Expo is the ability of the user to vary the scale of the microenvironments to individual model applications. This feature is important because it allows the user to relate the size of a microenvironment to the potential for exposure from different pollutants.

In TRIM.Expo, the inhalation exposure of each individual or cohort is determined by an exposure-event sequence specific to the individual or cohort. Furthermore, the exposure-event sequence for a particular cohort applies to all individuals in that cohort. The exposure-event sequence is a chronologically-ordered series of events which identifies locations and activities and the amount of time spent performing each activity in each location. In addition, the exposure-event sequence is specific to the day of the week. The information about the day of the week is obtained from the activity pattern database. Each exposure-event sequence consists of a series of events with durations ranging from 1 to 60 minutes. Once an exposure-event sequence is selected to represent the daily exposure of a cohort, it is followed through for an entire 24-hour period. A different exposure-event sequence is selected for each day in the study period. The TRIM.Expo module retains the information about the day of the week and season throughout the entire analysis because these variables can affect exposure results. Each exposure event assigns the cohort to a particular combination of exposure district, microenvironment, and activity (*e.g.*, cooking, playing, resting). Although no two individuals' exposure will be *exactly* the same due to the myriad of factors that affect a person's exposure; for the purposes of estimating a population's exposure, especially considering the dearth of long-term time/activity information for a large enough cross section of the population, the model uses the simplifying assumption that all individuals within a particular cohort have the same exposure.

Information about the exposure-event sequences can be obtained by sampling from a human activity database. The human activity database is made up of diary and telephone survey records which identify a study participant's daily activities and locations during a 24-hour period. Because each participant of most activity diary studies provides data for only a few days, the construction of a longer exposure-event sequence requires either the repetition of data from one participant or the use of data from multiple participants. The latter approach is being used in the initial development of TRIM.Expo to better represent the variability of exposure that is expected to occur among the persons included in the cohort. The need to extrapolate short-term activity diary information to chronic exposure assessments is a recognized shortcoming in long-term exposure studies. There is a critical need for data on long-term activity patterns that can be used for constructing year-long exposure-event sequences. This issue, and discussion of an alternative statistical approach for augmenting short-term activity pattern diary data, are expanded upon in Section 5.4.2.

For the initial development of a TRIM.Expo Prototype, a compilation of time-activity surveys will be used for a cohort analysis. These surveys have been organized into a single database called the Consolidated Human Activity Database (CHAD) which was described previously in Section 4.3.3. The developers of CHAD have supplemented the activity pattern survey information with data showing the day of the week that a diary entry was made and also the maximum outdoor air temperature for that day. Knowledge of the day of the week is important when constructing exposure-event sequences since human activities are usually quite different for weekdays than they are on weekends (U.S. EPA 1996a). Providing information about the maximum outdoor air temperature that occurred on the day that a diary entry was made is a useful method for selecting activity data that account for seasonal variation when constructing year-long exposure-event sequences. For an individual analysis, the user must either provide demographic information about the individuals so that appropriate activity pattern data can be extracted from CHAD, or directly provide the time sequence of exposure district/microenvironment/activity pattern combinations, as well as the demographic data related to breathing rate (*i.e.*, age, gender, body weight).

5.1.5 ESTIMATE POLLUTANT CONCENTRATION AND VENTILATION RATE ASSOCIATED WITH EACH EXPOSURE EVENT

The exposure-event sequence defined for each individual or cohort is used to determine a corresponding sequence of exposures, event-by-event. Each inhalation exposure is defined by a pollutant concentration and a ventilation rate indicator. The applied dose is a function of the pollutant concentration, the demographic characteristics of the individual or cohort affecting breathing rate, and the ventilation rate values assigned to the activity.

The first step in estimating the microenvironmental pollutant concentrations is to estimate the ambient pollutant concentrations. As discussed in Section 5.1.1, these are estimated from either fixed-site monitoring data, through the use of an air dispersion model, or from TRIM.FaTE. Next, microenvironmental concentrations are calculated from ambient concentrations and data on microenvironmental emission sources for indoor microenvironments (1) through the use of mass balance algorithms (described in Section 5.2.1), (2) with intermedia transfer factors, and/or (3) with measurements of concentration increments associated with indoor sources. Intermedia transfer factors are empirically derived and relate outdoor concentrations to the concentration contributions in the various indoor microenvironments used in TRIM.Expo. In addition, measurements of concentration increments associated with certain outdoor microenvironments (*e.g.*, gas stations, parking garages) may be used if they are not modeled or monitored explicitly. For other special outdoor microenvironments (*e.g.*, near roadways), statistical analysis of ambient-to-microenvironment concentration relationships may be used to estimate microenvironmental concentrations based on fixed-site monitoring data.

Concentrations are determined for each microenvironment in each exposure district for each time step in the exposure-event sequence. These concentrations constitute the values for $C_m(i,k,l,t)$ in Equation 4-1. For inhalation, the concentrations are calculated for air only; therefore, the only exposure medium *m* in Equation 4-1 is air.

In TRIM.Expo, an array of microenvironmental pollutant concentration values C_m are created for each individual or cohort. Each array consists of a set of year-long sequences of hourly-averaged C_m values; one for each combination of exposure district, microenvironment, and activity. In the initial development of TRIM.Expo, the district will be either the home, work, or school district specified for the individual or cohort. For an exposure event during time step *t*, an individual or cohort is assigned the value of C_m specified for that time step in the designated exposure-district/microenvironment/activity sequence.

In addition to the pollutant concentration, a ventilation rate (V_E) value is estimated for each exposure event. V_E is expressed as liters of air respired per minute (liters min^{-1}). The procedure for calculating V_E is summarized below. An approach to estimate the various values and relationships needed to model the ventilation rate using Equations 5-3, 5-4, and 5-5 (below) is described in Appendices C and D of Johnston et al. (1999).

The CHAD database provides an activity indicator for each exposure event. Each activity type is assigned a distribution of values for the metabolic equivalent of work (*MET*). The *MET* is a dimensionless quantity defined by the ratio:

$$MET = EE/RMR \tag{5-1}$$

where *EE* is the rate of energy expenditure during a particular activity (expressed in kcal/min), and *RMR* is a person's typical resting metabolic rate (also expressed in kcal/min).

A probabilistic procedure is used to assign a *RMR* value to cohort for a typical 365-day exposure period. An *EE* value is calculated for each exposure event by the equation:

$$EE_a(r,p,z) = [MET(r,p,z)][RMR(z)] \tag{5-2}$$

in which $EE_a(r,p,z)$ is the average energy expenditure rate (kcal min^{-1}) for cohort *z* during exposure event *r* on day *p*; $MET(r,p,z)$ is a value randomly selected from the distribution of MET values associated with each activity type in CHAD; and $RMR(z)$ is the *RMR* value randomly generated for cohort *z*.

Energy expenditure requires oxygen, which is supplied through ventilation (respiration). Let $ECF(y)$ indicate an energy conversion factor defined as the volume of oxygen required to produce one kilocalorie of energy in person *y*. The oxygen uptake rate (VO_2) associated with a particular activity can be expressed as:

$$VO_2(r,p,z) = [ECF(y)][EE_a(r,p,z)] \tag{5-3}$$

in which $VO_2(r,p,z)$ has units of liters oxygen min^{-1}, $ECF(y)$ has units of liters oxygen kcal^{-1}, and $EE_a(r,p,z)$ has units of kcal min^{-1}. The value of $VO_2(r,p,z)$ is determined from $MET(r,p,z)$ by substituting Equation 5-2 into Equation 5-3 to produce the relationship:

$$VO_2(r,p,z) = [ECF(y)][MET(r,p,z)][RMR(y)] \tag{5-4}$$

Ventilation rate (V_E) tends to increase as VO_2 increases up to the point of maximum oxygen uptake (VO_{2max}). The relationship is known to be non-linear, with the slope of the relationship usually increasing at higher values of VO_2. The relationship between $V_E(r,p,z))$ and $VO_2(r,p,z)$ is modeled by the generic equation:

$$ln[V_E(r,p,z)/BM(y)] = \mathrm{a} + (\mathrm{b})\{ln[VO_2(r,p,z)/BM(y)]\} + d(y) + e(r,p,z) \tag{5-5}$$

in which $V_E(r,p,z)$ is the V_E value associated with the r^{th} event of day p for person y, $BM(y)$ is the body mass assigned to person y, and a and b are constants determined by the age and gender of person y. The term $d(y)$ is a random variable selected for each person from a normal distribution with mean equal to zero and standard deviation equal to σ_d. The term $e(r,p,z)$ is a random variable selected for each individual event from a normal distribution with mean equal to zero and standard deviation equal to σ_e.

5.1.6 EXTRAPOLATE THE COHORT INHALATION EXPOSURES TO THE POPULATIONS OF INTEREST

For a population analysis, the inhalation exposures calculated for the cohorts can be extrapolated to the larger general population by estimating the number of individuals in each cohort. First, the population of each demographic group that resides within a particular exposure district is extracted from census data specific to that district. This gives an estimate of the population of each non-commuting cohort residing within each exposure district. Then, as described in Equation 4-12 (shown below), the populations of the commuting cohorts (assumed to include all cohorts of working adults and school children) are determined by the expression:

$$com(dg,h,w,b) = pop(dg,h,b) \times com(h,w) \,/\, com(h)$$

where $com(dg,h,w,b)$ is the number of persons in the commuting cohort associated with demographic group dg, residing in exposure district h (*i.e.*, the home district), commuting to exposure district w (*i.e.*, the commute district) and having attribute b (*e.g.*, the incidence of a particular disease or ailment). The $pop(dg,h,b)$ is the population of demographic group dg residing in exposure district h that has attribute b. The $com(h,w)$ is the number of commuters in all demographic groups that commute from their residence in exposure district h to work or school in exposure district w, and $com(h)$ is the total number of commuters that reside in exposure district h.

5.2 PRESENTATION OF THE MODEL ALGORITHMS BY MICROENVIRONMENTAL LOCATION

The TRIM.Expo module will be able to model inhalation exposures for several indoor, in-vehicle, and outdoor microenvironments. As mentioned earlier in this chapter, a user will have the ability to specify additional microenvironments of various scales to fit individual modeling requirements. In this section, the general algorithms are presented for each of these locations. The methodology presented here for calculating indoor, in-vehicle, and outdoor microenvironmental concentrations conforms to the requirements specified earlier for TRIM framework development. One of the important goals for modeling microenvironmental concentrations is that the methodology conserve mass, where appropriate and feasible. Alternative methodologies will also be included as options when the information required for mass balance is not available.

5.2.1 MICROENVIRONMENTAL LOCATIONS SPECIFIC TO INDOOR AIR AND INSIDE VEHICLES

The TRIM.Expo module will include algorithms that can be used to estimate pollutant concentration for several indoor microenvironments, such as residences, residential garages, the work place, school, and other indoor locations such as restaurants and stores. In addition, the inside of passenger vehicles, such as automobiles and buses, will be treated similarly to the indoor microenvironment. In general, there are two types of contributions to the pollutant concentrations in these microenvironments: infiltration of air from outside the microenvironment's boundaries, and direct emission of a pollutant of concern from a source within the microenvironment. Infiltration will be modeled by TRIM.Expo using either a mass balance approach, described below, or an assumed transfer factors (ME factors).

For indoor emission sources, TRIM.Expo will provide two options. For the first option, information on the emission rate (in units of mass/time) for a source is used as an input to the mass balance model. For the second option, sample values are drawn stochastically from a distribution that relates the presence of an indoor source in a particular microenvironment to incremental increases in pollutant levels. For example, to estimate the contribution to pollutant concentrations in the home from tobacco smoking using the first option, the user may specify the frequency of smoking (*e.g.*, the number of cigarettes per hour), which TRIM.Expo will use to derive a pollutant emission rate for input to the mass balance equation. If smoking frequency information is unavailable, the user may simply indicate that smoking occurs in the home. In that case, TRIM.Expo will estimate the contribution to pollutant concentrations from smoking by sampling from a distribution of the measured increase in pollutant concentrations in homes of smokers. Alternatively, the user may supply his or her own distributional data.

The TRIM.Expo mass balance model and description are adapted from Johnson et al. (1996b). The mass balance model is based on the generalized mass balance model presented by Nagda et al. (1987) for a single indoor compartment. As originally proposed, this model uses the assumption that pollutant concentration decays indoors at a constant rate. However, Johnson et al. (1996b) reports that pollutant decay rate is a function of the indoor pollutant concentration.

Therefore, in TRIM.Expo, the model of Nagda and co-workers was revised to incorporate an alternative assumption that the indoor decay rate is proportional to the indoor concentration. The resulting model is expressed by the differential equation:

$$\frac{d}{dt}C_{in} = (1 - F_B)\ \nu C_{out} + \frac{S}{cV} - M\nu C_{in} - F_d C_{in} - \frac{qFC_{in}}{cV} \tag{5-6}$$

where:

C_{in}	=	indoor concentration (mass/volume)
F_B	=	fraction of the outdoor pollutant concentration intercepted by the building or structure (dimensionless fraction)
ν	=	air exchange rate (1/time)
F_d	=	pollutant decay coefficient (1/time)
C_{out}	=	outdoor concentration (mass/volume)
S	=	indoor generation rate (mass/time)
cV	=	effective indoor volume where *c* is a dimensionless fraction (volume)
M	=	mixing factor (*i.e.*, the portion of the ventilation air flow that is completely mixed with room air) (dimensionless fraction)
q	=	flow rate through air-cleaning device (volume/time)
F	=	efficiency of the recirculation air-cleaning device (dimensionless fraction)

The model is further generalized to include a mixing factor for outdoor air infiltration and the possibility of infiltrated air from outside being filtered as follows:

$$\frac{d}{dt}C_{in} = (1 - F_B)\ M\nu_u C_{out} + \frac{S}{cV} - M\nu_u C_{in} - F_d C_{in} - \frac{qF_1 C_{in}}{cV} + (1 - F_2)\ M\nu_f C_{out} - M\nu_f C_{in} \tag{5-7}$$

where:

ν_u	=	air exchange rate, unfiltered (1/time)
ν_f	=	air exchange rate, filtered (1/time)
F_1	=	efficiency of the recirculation air-cleaning device (dimensionless fraction)
F_2	=	efficiency of the outdoor makeup-air cleaning device (dimensionless fraction)

Equation 5-7 can be simplified by substituting a "penetration factor," F_p, for the fraction of the outdoor concentration intercepted by the enclosure and an "effective volume," V_e, for cV. F_p and V_e are given by Equations 5-8 and 5-9, respectively:

$$F_p = 1 - F_B \tag{5-8}$$

$$V_e = cV \tag{5-9}$$

Substituting Equations 5-8 and 5-9 into Equation 5-7 results in:

$$\frac{d}{dt}C_{in} = F_p\ M\nu_u C_{out} + \frac{S}{V_e} - M\nu_u C_{in} - F_d C_{in} - \frac{qF_1 C_{in}}{V_e} + (1 - F_2)\ M\nu_f C_{out} - M\nu_f C_{in}$$

(5-10)

Combining and rearranging terms yields:

$$\frac{d}{dt}C_{in} = M(F_p\ \nu_u + [1 - F_2]\nu_f)C_{out} + \frac{S}{V_e} - M(\nu_u + \nu_f)C_{in} - F_d C_{in} - \frac{qF_1 C_{in}}{V_e}$$

(5-11)

Equation 5-11 can be simplified by combining terms proportional to C_{in}:

$$\frac{d}{dt}C_{in} = M(F_p\ \nu_u + [1 - F_2]\nu_f)C_{out} + \frac{S}{V_e} - \nu' C_{in} \tag{5-12}$$

where:

$$\nu' = M(\nu_u + \nu_f) + F_d + \frac{qF_1}{V_e} \tag{5-13}$$

It can be shown that Equation 5-12 has the following approximate solution:

$$C_{in}\ (t) = k_1 C_{in}\ (t–\Delta t) + k_2 C'_{out} + k_3 \tag{5-14}$$

where:

$$k_1 = e^{-\nu'\Delta t} \tag{5-15}$$

$$k_2 = \frac{M(F_p \nu_u + [1 - F_2]\nu_f)}{\nu'}\ (1 - k_1) \tag{5-16}$$

$$k_3 = (S / \nu' V_e)\ (1–k_1). \tag{5-17}$$

C'_{out} is the average value of the outdoor concentration over the interval t to $t + \Delta t$.

The average indoor concentration for hour h is given by C'_{in} in the expression:

$$C'_{in}\,(h_0) = a_1 C_{in}\,(h\text{–}1) + a_2\, C'_{out}\,(h_0) + a_3 \tag{5-18}$$

where $C_{in}(h\text{-}1)$ is the instantaneous indoor concentration at the end of the preceding hour and $C'_{out}(h)$ is the average outdoor concentration for hour h. Also, a_1, a_2, and a_3 are given by:

$$a_1 = z(h_0) \tag{5-19}$$

$$a_2 = \frac{M(F_p \nu_u + [1 - F_2]\nu_f)}{\nu'}\,(1 - z(h0)) \tag{5-20}$$

$$a_3 = \frac{S}{\nu' V_e}\,(1 - z(h0)) \tag{5-21}$$

$$z(h_0) = (1 - e^{-\nu'}) / \nu' \tag{5-22}$$

A steady-state version of the mass balance model (Equation 5-12) can be developed if it is assumed that the change in indoor concentration with time is zero.

When information about the indoor emission source strength is not available, a_3 may be sampled from a distribution of measured incremental concentrations associated with the presence of the indoor source. Some of these distributions will be included in TRIM.Expo. The user will also have the option of supplying his or her own indoor source distribution.

5.2.2 MICROENVIRONMENTAL LOCATIONS SPECIFIC TO AMBIENT AIR

One of the options for obtaining pollutant concentration data for outdoor locations in TRIM.Expo is through the use of air dispersion modeling. The output files from TRIM.FaTE or another air model may be used if data are properly formatted. Regardless of the method for modeling the dispersion of pollutants, the ambient pollutant concentrations at receptors must be related to geopolitically defined exposure districts where people live, work, or attend school. For example, suppose the user wants to design an exposure analysis to cover a large city and the surrounding suburbs with an areal extent of 100 km within an urban area. For this example, a typical TRIM.Expo exposure analysis could be conducted using census tracts as the exposure districts. In that case, time sequences of hourly-averaged estimates of outdoor pollutant concentrations for each census tract in the study area are required. These concentration estimates could come directly from the air dispersion model, if census tract centroids were used as the model receptors, or they may be derived from concentration estimates made at other receptor points in the study area. There are several ways to do this.

If the spatial resolution of model receptors is finer than the spatial resolution of exposure districts, concentrations can be assigned to exposure districts from modeling receptors that fall within each exposure district according to the formula:

$$\overline{C_i}(v,t) = (1/v_i)\sum C(c,i,t) \tag{5-23}$$

where $\overline{C}_i\,(v,t)$ is the average ambient pollutant concentration in exposure district i from the v modeled receptor points for time step t, v_i is the number of receptor points in exposure district i, and $C(c,i,t)$ is the ambient concentration at receptor point c within exposure district i during time step t. The values of $C(c,i,t)$ are summed over the total number of receptor points in each exposure district (*i.e.*, v_i).

If the spatial resolution of modeled receptor points is more coarse than the resolution of exposure districts, concentrations can be spatially interpolated to the exposure district centroids using the formula:

$$C(i,t) = \frac{\sum[C(c,t)\ /\ d^2(c,i)]}{\sum[1\ /\ d^2(c,i)]} \tag{5-24}$$

where: $C(c,t)$ = estimated concentration at receptor point c for time step t
$d(c,i)$ = distance from a receptor point c and the centroid of exposure district i.

Alternatively, exposure districts could be redefined as aggregations of contiguous census tracts, with each tract assigned the concentration estimate at the nearest modeled receptor.

The second method for obtaining a time sequence of outdoor concentrations for each exposure district is through the use of monitored ambient data. There are several limitations to the use of monitoring data for air toxics. At present, the number of routine monitoring sites for air toxics is much smaller than for criteria air pollutants. Also, air toxics are often measured as 24-hour integrated samples taken every sixth or twelfth day. However, with increased concern about health effects from toxic air pollutants, EPA plans to increase the extent of its monitoring efforts. In addition, future development of TRIM.Expo will make it easier to use a variety of mathematical tools and spatial interpolation techniques such as krieging for estimating outdoor pollutant concentrations.

Because the spatial resolution of monitors, even for criteria air pollutants, is typically rather coarse, it is customary to specify exposure districts by assigning concentrations to census tracts according to the values measured at the nearest monitor. Using this method, an air pollutant's concentration is assumed to be the same for all census tracts within a particular exposure district. In making these assignments, attention should be paid to the spatial area of representation for the monitors. The EPA has four different monitor classifications as follows:

1. Micro-scale: representative of from a few to 100 m;

2. Middle-scale: representative from 100 to 500 m;

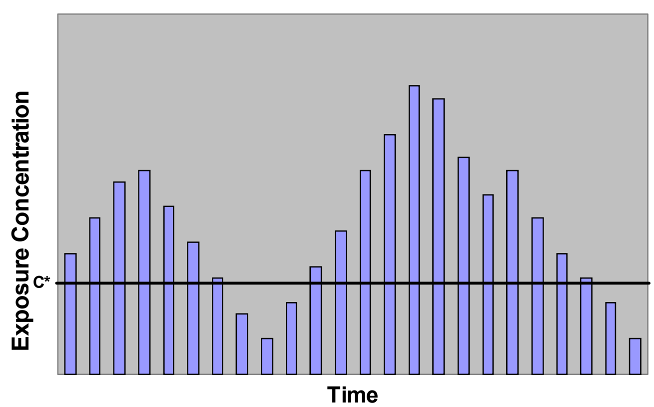
3. Neighborhood-scale: representative from 0.5 to 4 km; and

4. Urban-scale: representative from 4 to 50 km.

There are a number of outdoor locations that may have enhanced pollutant concentrations, such as gasoline stations, parking garages, and near roadways. As noted above, if these microenvironments are not modeled or monitored explicitly for the particular study area, it may be necessary to derive concentration estimates from measurements in those microenvironments from other locations. Alternatively, it may be necessary to derive the concentrations from the more generalized outdoor estimates and information about the relationship between the generalized outdoor concentration and the outdoor microenvironment (*e.g.*, the distribution of ratios of CO concentrations near roadways to concentrations at other outdoor locations). Some of this information will be provided in TRIM.Expo. The user will also have the option of providing his or her own distributions.

5.3 INTEGRATION OF EXPOSURE ACROSS MULTIPLE LOCATIONS AND TIMES

Figure 5-2
Hypothetical Exposure Profile Covering 24 Time Steps



The TRIM.Expo module will have the ability to integrate exposures of varying durations across numerous microenvironments. This is accomplished by TRIM.Expo's exposure characterization process. The purpose of the exposure characterization process is to combine and simultaneously track all of the relevant information needed to assess exposures across several exposure media occurring with varying time-durations. In this chapter, the exposure media of concern are outdoor and indoor air. As noted above, for each individual or cohort, a sequence of exposure events is defined. Exposure-event sequences are chronological sets of events that define the time-activity allocation of the individual or cohort. A simple example of an exposure-event sequence is presented in Table 4-6 (Section 4.2.5). The exposure-event sequence tracks the individual or cohort by (1) exposure district, (2) microenvironment, and (3) activity at each time step. Each exposure event will be associated with an exposure concentration and a breathing rate. The TRIM.Expo algorithms will use the information on the exposure concentration at each time step to create an exposure time series or profile. Figure 5-2 shows an example of an exposure profile covering 24 time steps. By combining the exposure concentration and the breathing rate at each time step, TRIM.Expo will also create a potential dose profile (see Section 4.1.2). McCurdy (1997) summarizes the definition of dose profile as the collection of the instantaneous intake doses over a time interval (t_0, t_1), where the instantaneous intake dose is the rate at which the pollutant penetrates into the target at a given instant of time.

5.4 SUMMARY OF INPUTS AND VALUES

Because the types of data used in a TRIM.Expo exposure analysis are quite diverse, each one is described in a separate section below. These sections summarize these data inputs and provide values for them wherever possible.

5.4.1 DATA INPUTS FOR THE MASS BALANCE MODEL

The mass balance model (Equation 5-12) requires information on the air exchange rate, the building volume, the indoor generation of the pollutant, the fraction of the pollutant penetrating the building from outdoors, and the pollutant decay rate. Many of these parameters depend on several factors. For example, the fraction of pollutant mass in infiltration air that actually enters the building (*i.e.*, the penetration rate) depends upon the state of the pollutant (*i.e.*, whether it is a gas, a fine particle, or a coarse particle), the type of building construction, whether the building's windows are open, if windows are open, by how much, and the type of air conditioning and/or air handling system. Therefore, data are not available for every pollutant and every scenario.

Two factors that are important to the calculation of indoor concentrations which are not pollutant-specific are the air exchange rate and building volume. Data on these factors have been collected by numerous studies in different parts of the U.S. Some of these data were summarized in Johnson et al. (1999) for the pNEM/CO model and are shown in Tables 5-1 and 5-2. Table 5-1 shows the sources of information on the distributions for air exchange and building volumes. Table 5-2 shows the references for specific microenvironmental air exchange rate data. These microenvironments correspond to those currently used in pNEM/CO. Information on building volume and air exchange rate will need to be developed for additional microenvironments for TRIM.Expo system applications to other pollutants based on these and other databases.

Table 5-1
Distributions and References for Air Exchange and Building Volume Data

Parameter	Distribution of Parameter	Reference
Air exchange rate, exchanges/h: residence - windows closed	Lognormal distributions by season	Murray and Burmaster 1995
Air exchange rate, exchanges/h: residence - windows open	Lognormal distribution	Johnson, Weaver, Mozier et al., 1998
Air exchange rate, exchanges/h: nonresidential, enclosed microenvironments, including motor vehicles	See Table 5-2	See Table 5-2
Residential volume, cubic meters	Lognormal distribution	Bureau of Census 1995

Table 5-2
Distributions and References for Specific Microenvironmental Air Exchange Rate Data

Microenvironment		Activity Diary Locations Included in Microenvironment	Distribution of Air Exchange Rate	
General Location	Specific Location		Distribution Type	Source of Data
Indoors	Nonresidence A	Service station or auto repair	Lognormal	a
Indoors	Nonresidence B	Other repair shop Shopping mall	Lognormal	a
Indoors	Nonresidence C	Restaurant Other indoor location Auditorium	Lognormal	a
Indoors	Nonresidence D	Store Office Other public building	Lognormal	a
Indoors	Nonresidence E	Health care facility, School, Church, Manufacturing facility	Lognormal	b
Indoors	Residential garage	Residential garage	Lognormal	a
Vehicle	Automobile	Automobile	Lognormal	c
Vehicle	Other	Bus, Truck, Bicycle, Motorcycle, Train/subway, Other vehicle	Lognormal	c
Vehicle	Airplane	Airplane	NA	--

[a] Data set containing all non-school AER values provided by Turk et al. (1989) and CEC (Lagus Applied Technology, Inc. 1995).
[b] Data set containing all AER values provided by Turk et al. (1989) and CEC (Lagus Applied Technology, Inc. 1995).
[c] Ott, Switzer, and Willis (1994).

5.4.2 DATA INPUTS FOR TIME/ACTIVITY PATTERNS

The time/activity data for use in TRIM.Expo were obtained from CHAD. The CHAD is comprised of approximately 17,000 person-days of 24-hour time/activity data developed from eight surveys (Glen et al. 1997). The surveys include probability-based recall studies conducted by EPA and the California Air Resources Board, as well as real-time diary studies conducted in individual U.S. metropolitan cities using both probability-based and volunteer subject panels. All ages of both genders are represented in CHAD. The data for each subject consist of one or more days of sequential activities in which each activity is defined by start time, duration, activity type (140 categories), and microenvironment classification (110 categories). Activities vary from one minute to one hour in duration, with longer activities being subdivided into clock-hour durations to facilitate exposure modeling. Refer to Section 4.3.3 for a more detailed discussion of CHAD.

Extrapolating the information from short-term recall surveys to longer-term chronic exposure assessments is currently a potential source of uncertainty in exposure modeling. Additional research into longer term activity pattern data is needed to address this shortcoming. The EPA's Office of Research and Development is embarking on research to develop statistical methods to develop long-term exposure profiles from the activity pattern survey data that is currently available (Ozkaynak 1999). As part of this effort, careful analysis of multiday diaries from currently available surveys will be used to develop alternative statistical approaches for generating correlated diaries for activity and consumption information at the individual level. Once these statistical approaches are developed, they will be incorporated into TRIM.Expo as appropriate. Ultimately, year-long or greater measured exposure data will need to be collected to verify the validity of these statistical techniques.

A statistical technique developed to augment the activity pattern data for pNEM/CO will be used during the initial development of TRIM.Expo. Earlier versions of pNEM/CO defined cohorts solely according to home district, demographic group, work district (if applicable), and residential cooking fuel. The new feature installed in pNEM/CO (Version 2.0) permits the user to specify a "replication" value (n) such that the model will produce n cohorts for each combination of the above four indices. Because pNEM/CO uses a Monte Carlo process to construct an activity pattern for each cohort, each of the n cohorts associated with a particular combination of home district, demographic group, work district, and residential cooking fuel is associated with a distinct exposure sequence. The replication feature permits the analyst to divide the population of interest into a larger number of smaller cohorts; a process which pNEM/CO's developers report decreases the "lumpiness" of the exposure simulation. For example, if a replication value of five (n = 5) is specified, the pNEM/CO model analyzes five times the number of cohorts it would have considered if the cohorts had been defined solely by home district, demographic group, work district, and residential cooking fuel. The use of replication values is a technique that is intended to enhance the utility of existing data while more robust statistical techniques are developed and additional data are collected on chronic or longitudinal exposures of individuals within the population.

5.4.3 DATA INPUTS FOR VENTILATION RATE

As described in Section 5.1.5, CHAD provides an activity indicator for each exposure event. In turn, a distribution of values for the ratio of oxygen uptake rate to body mass (referred to as metabolic equivalents or "METs") is provided for each activity type listed in CHAD. The forms and parameters of these distributions were determined through an extensive review of the exercise and nutrition literature. The primary source of distributional data was a compendium developed specifically to facilitate the coding of physical activities and to promote comparability across studies by Ainsworth et al. (1993). Table 5-3 contains a list of the parameters used in pNEM/CO (Version 2.0) for estimating ventilation rates.

Table 5-3
Parameters Used to Estimate Ventilation Rates

Parameter	Abbreviation	Functional Form	Source of Data
Body mass	BM	Lognormal distribution	Brainard and Burmaster 1992
Metabolic equivalence	MET	Distribution specified in CHAD Database	Johnson et al. 1999
Resting metabolic rate	RMR	Regression equations specific to age and gender	Schofield 1985, as compiled by Johnson et al. 1999
Normalized oxygen uptake rate	NVO_{2max}	Normal distribution	Åstrand 1960, Mercier et. al. 1991, Katch and Park 1975, Heil et. al. 1995, Mermier et al. 1993, Rowland et al. 1987